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Title: presentation

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Li, Xuan

Intended for: Sant Fe jets workshop, 2020-02-03/2020-02-05 (santa Fe, New Mexico, United States)

Issued: 2020-02-03

Forward Physics at the EIC.
New Physics, detection, simulation needs.

Astrid Morreale, LANL

Santa Fe Jet Workshop, February 5, 2020

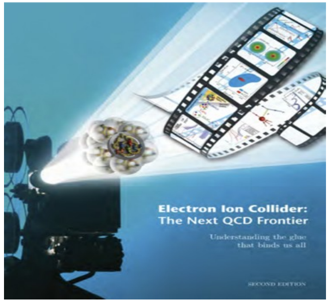
Outline

- Introduction
- Forward physics at the EIC
- Measuring Heavy Flavor observables
- Detector needs
- Simulation needs

EIC science from the white paper

Different fundamental physics problems in a wide x and Q^2 kinematic region:

- How quarks and gluons are distributed (momentum, space) within the nucleon/heavy nuclei?
- Who contributes to the spin of the proton and by how much?
- What happens to the gluon density in nuclei, does it saturate at high energy?



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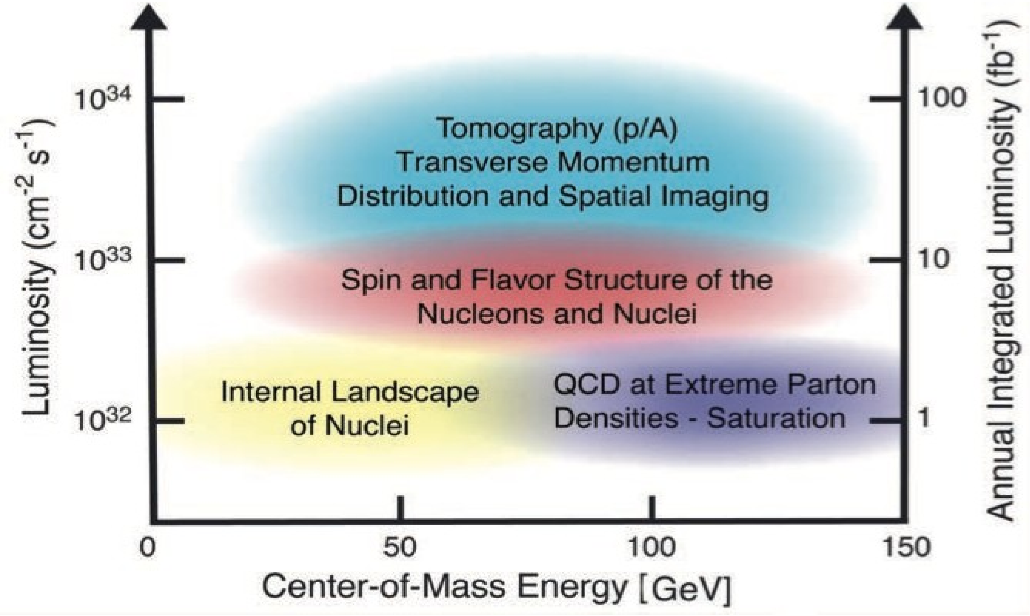

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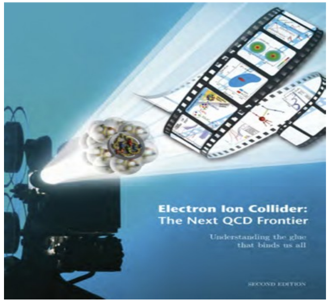

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Different fundamental physics problems in a wide x and Q^2 kinematic region:

- How quarks and gluons distributed (momentum, space) within the nucleon/heavy nuclei?
- Who and how contributes to the spin of the proton?
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The EIC will provide a clean environment to study the flavor dependent energy loss in nuclear medium.

- Heavy quarks (HQ: **c, d**) play a special role & address essential physics at the EIC
- This is accomplished by measuring the elementary particles that contain them: D-mesons and B-mesons

At the EIC HQ are produced from gluons carrying a large fraction x_B of the nucleons momentum (>0.1).

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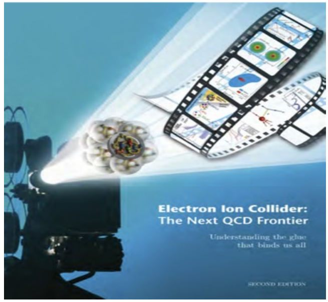

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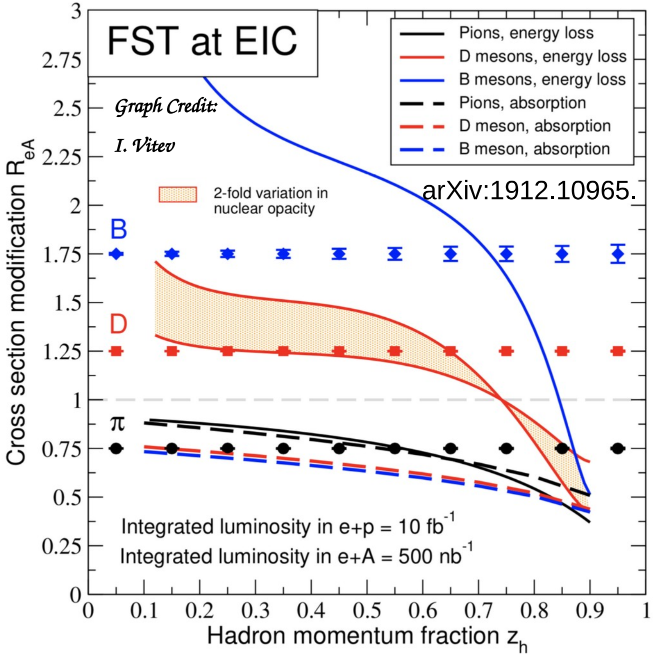
New LDRD project funded by LANL 2020022DR: Develop a new heavy flavor and jet program for the future EIC and carry out relevant detector R&D*.

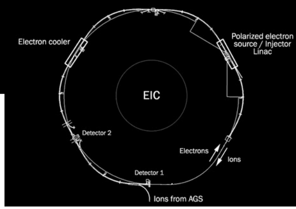
LDRD LABORATORY DIRECTED RESEARCH & DEVELOPMENT

* PIs: I. Vitev, X. Li

15 permanent staff, and several postdocs

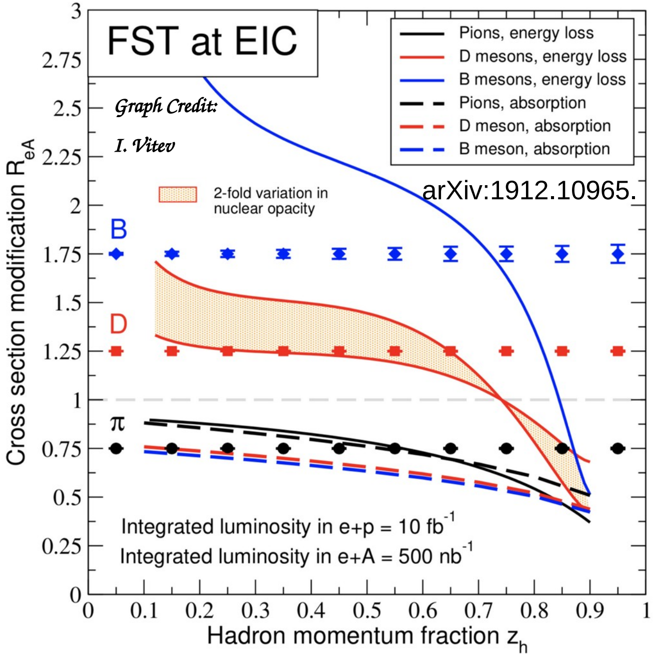
Focus: Energy Loss, Hadronization

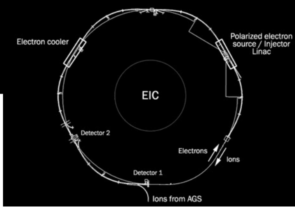




QCD energy loss:

Focus: Energy Loss, Hadronization

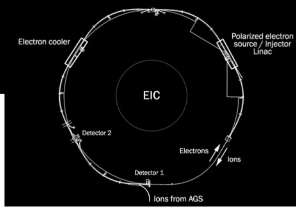


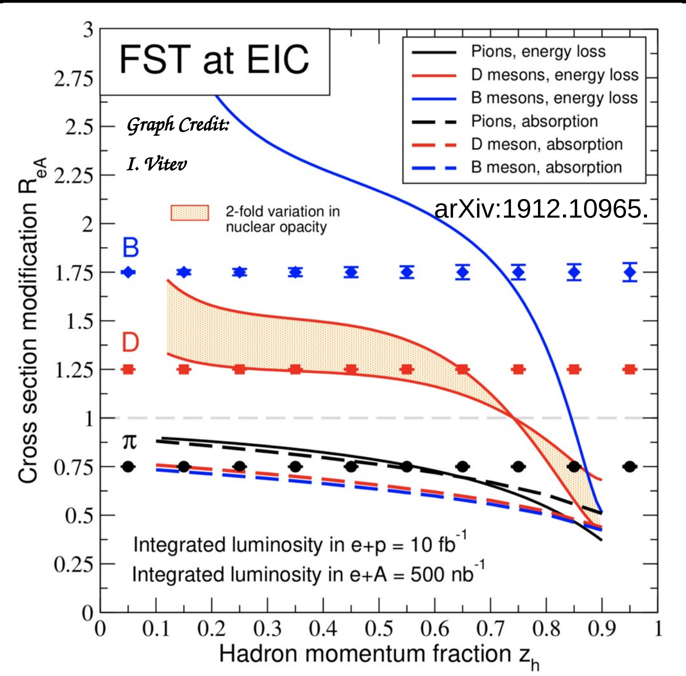


QCD energy loss:

The way in which HQ lose energy as the propagate through the nucleus is a key to our understanding particle transport in dense environment.
Transport coefficients as of this date remain largely unconstrained.

Focus: Energy Loss, Hadronization





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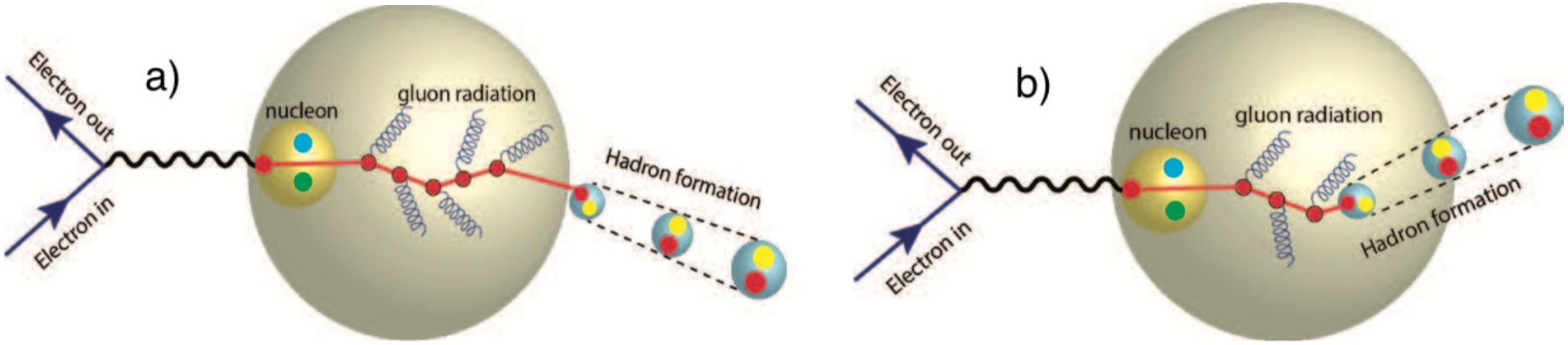
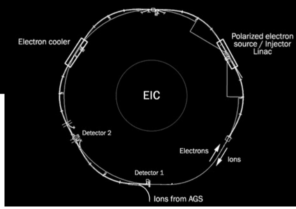
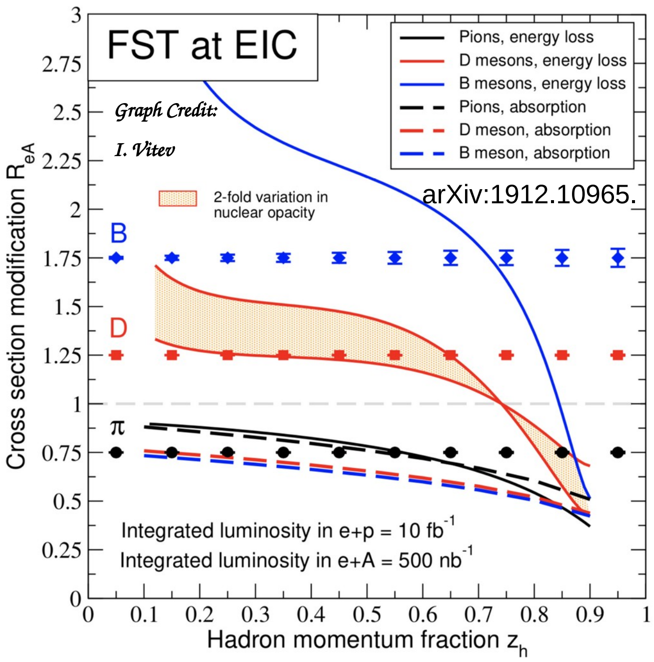


Figure credit: “An Assessment of U.S.-Based Electron-Ion Collider Science”

Focus: Energy Loss, Hadronization





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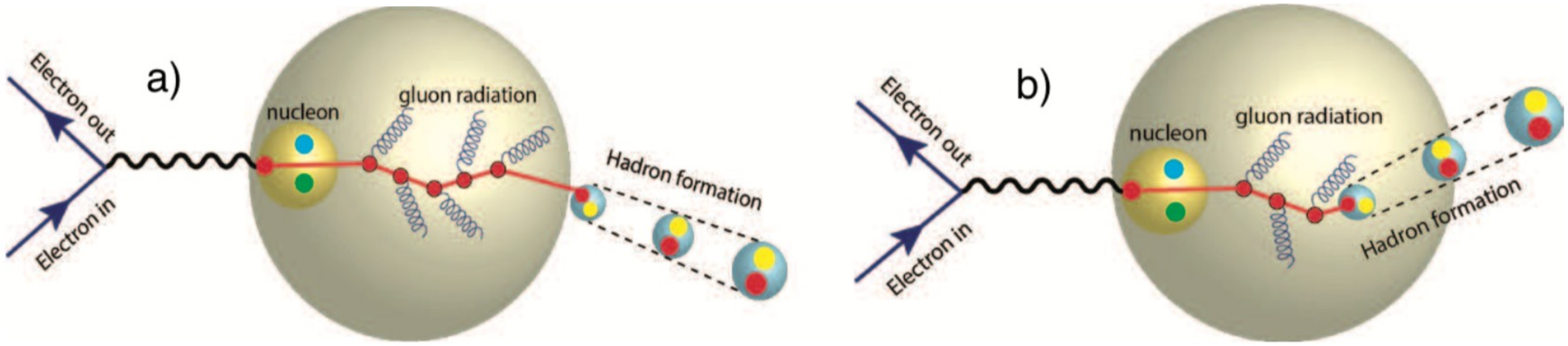

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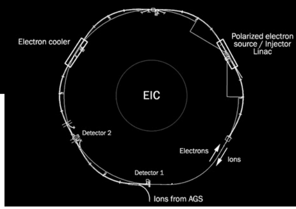
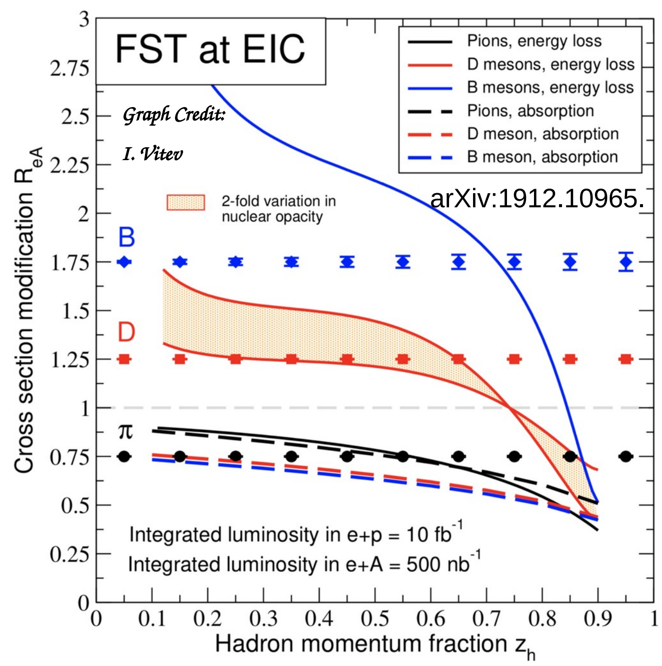
Focus: Energy Loss, Hadronization





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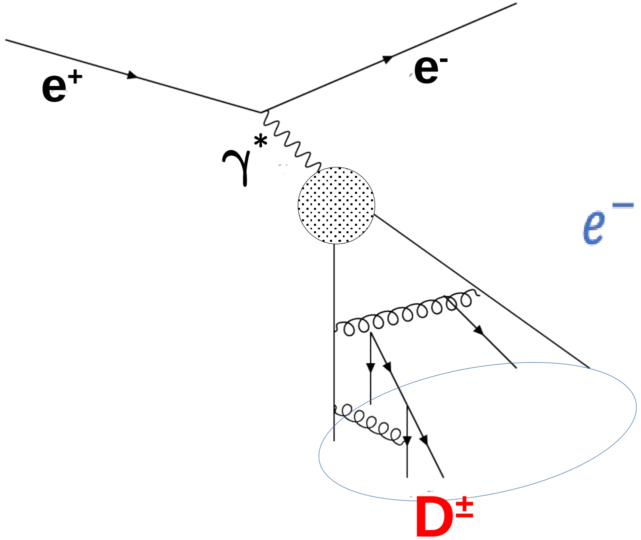
Large discriminating power between models of energy loss and hadronization in matter

Can **constrain nuclear opacities & transport properties to 20%**

Focus: Heavy flavor jets

Heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the forward-going nucleon/nucleus direction at the EIC.



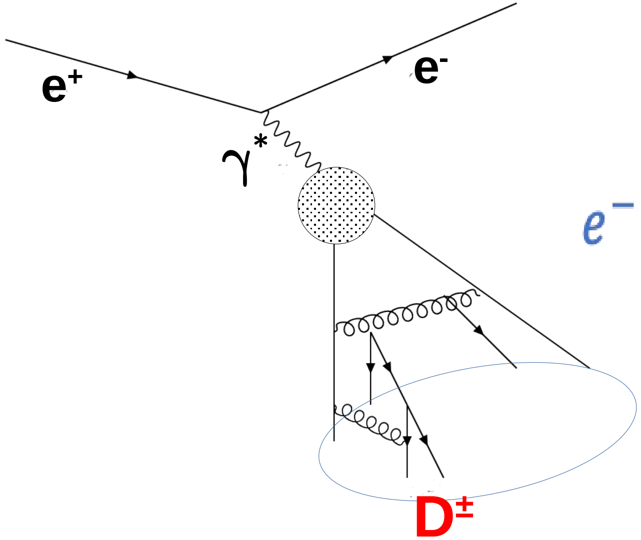
$$e^- + \mathrm{p} \rightarrow e^- + jet(D^{\pm}) + X$$

Focus: Heavy flavor jets

Heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the forward-going nucleon/nucleus direction at the EIC.

$$d\sigma^{Q} = f(x_a) \times d\hat{\sigma}_{lq} \times D^{Q}(Z_h)$$

- Distributions of partons in nucleons/nuclei (soft scale)
- Partonic cross-section (perturbative)
- Hadronization/evolution (soft scale)



$$e^- + p \rightarrow e^- + jet(D^{\pm}) + X$$

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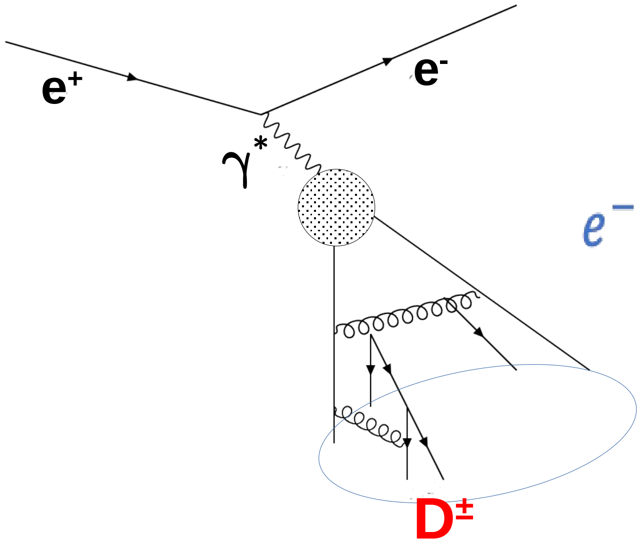
$$d\sigma^{Q} = f(x_a) \times d\hat{\sigma}_{lq} \times D^{Q}(Z_h)$$

- Determine the initial quark/gluon distribution functions in the poorly constrained kinematic region (x_B>0.1).
- Input for the evaluation of the quark/gluon fragmentation/hadronization processes.



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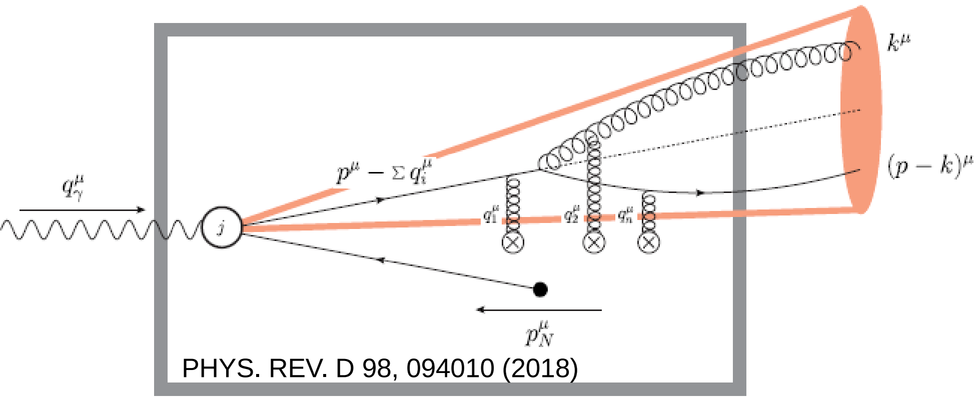
Focus: Heavy flavor jets

Insight to nuclear medium effects on hadron production (nPDFs modification , parton e-loss mechanisms)

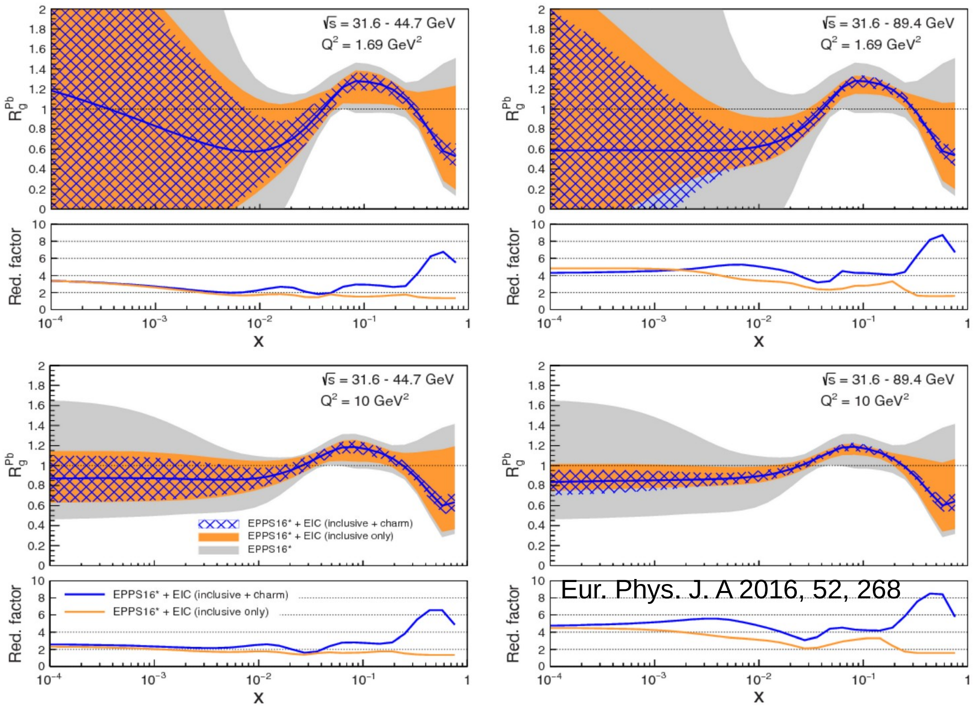
- Insight to hadronization processes

$e^- + A \rightarrow e^- + \text{jet}\ (D^{\pm}) + X$



PHYS. REV. D 98, 094010 (2018)

The grey box represents the medium (nucleus) and the orange cone represents the jet



Eur. Phys. J. A 2016, 52, 268

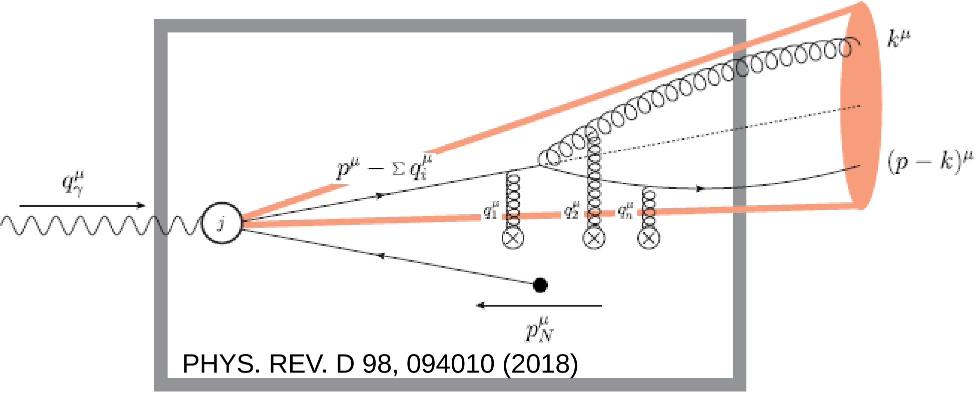
Uncertainty of gluon distributions in the lead nucleus, which is rather large at both low and high x.

Focus: Heavy flavor jets

Insight to nuclear medium effects on hadron production (nPDFs modification , parton e-loss mechanisms)

- Insight to hadronization processes

$e^- + A \rightarrow e^-$+jet ($D^{\pm}$) + X



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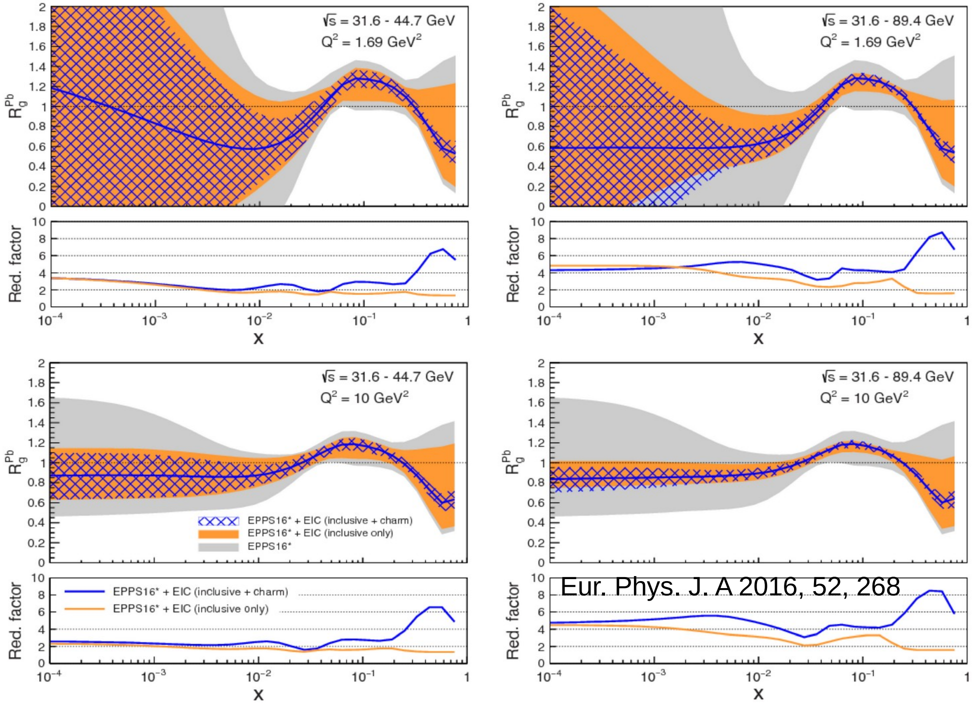

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→ comparison of measured cross section between ep and e-A collisions.

Measuring Heavy Quarks

Open heavy flavor measurements:
Unambiguous signature via **displaced vertices**

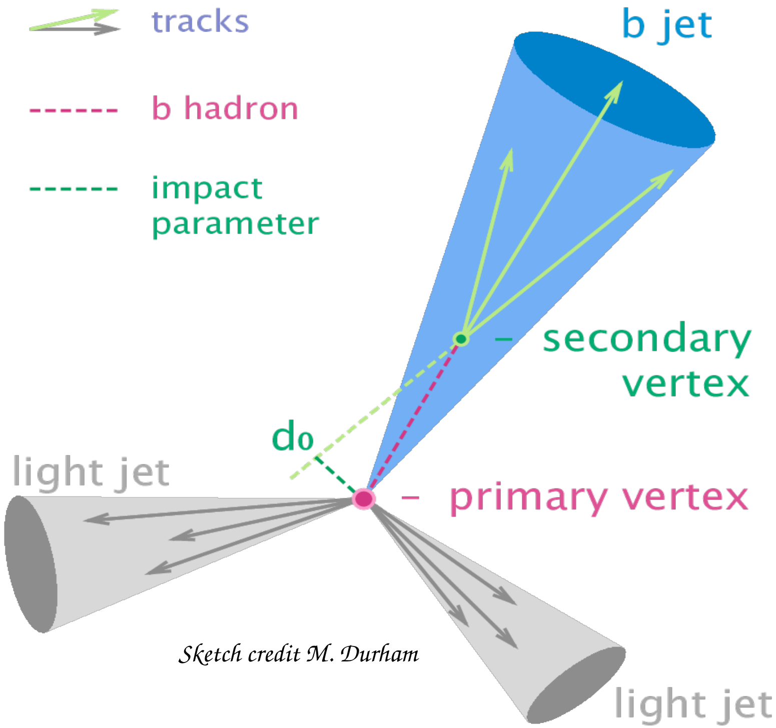
$$D^{\pm} \quad c\tau = 311.8\ \mu\mathrm{m}$$

$$B^{\pm} \quad c\tau = 491.1\ \mu\mathrm{m}$$

Need precise vertex determination
Need excellent spacial, timing resolution and low material budget.

→

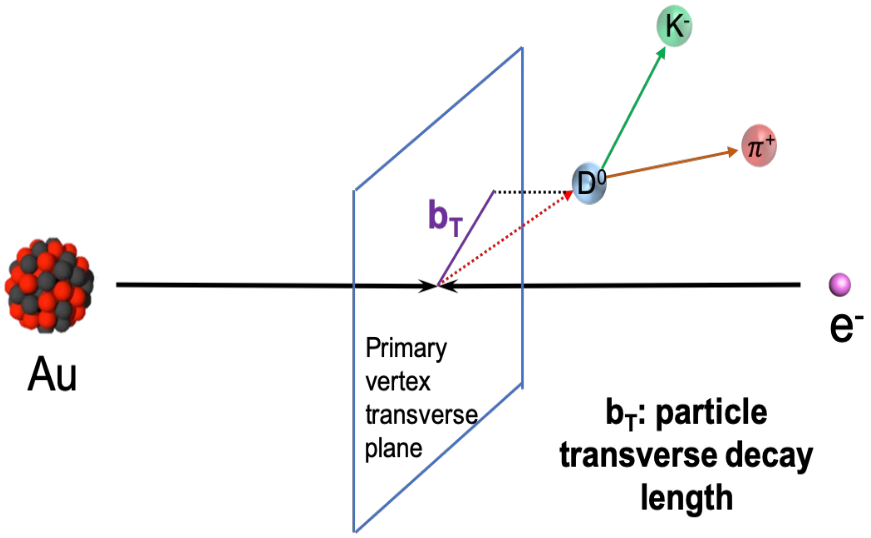
precision measurements needed for a robust heavy flavor physics program

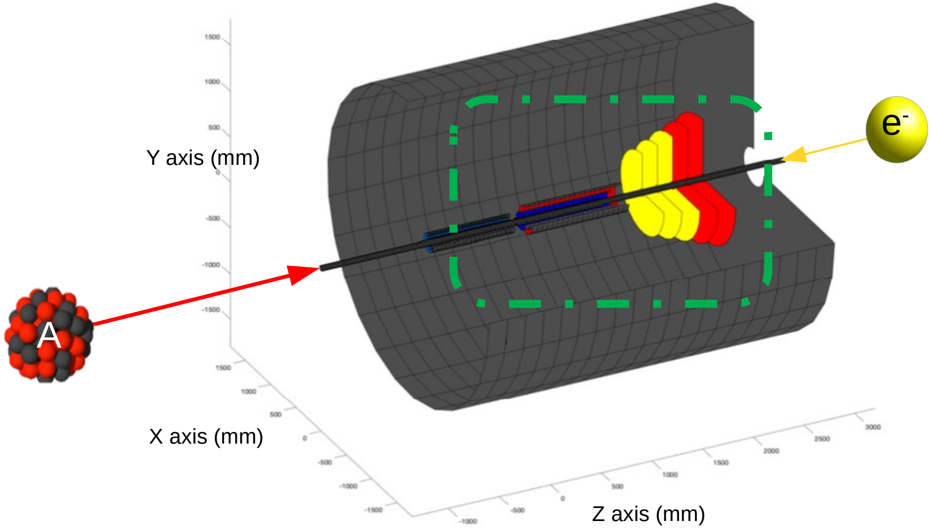


Sketch credit M. Durham

Proposed R&D: Forward Silicon Tracking detector

Goal is to measure heavy flavor products and their correlations in the forward direction at the EIC





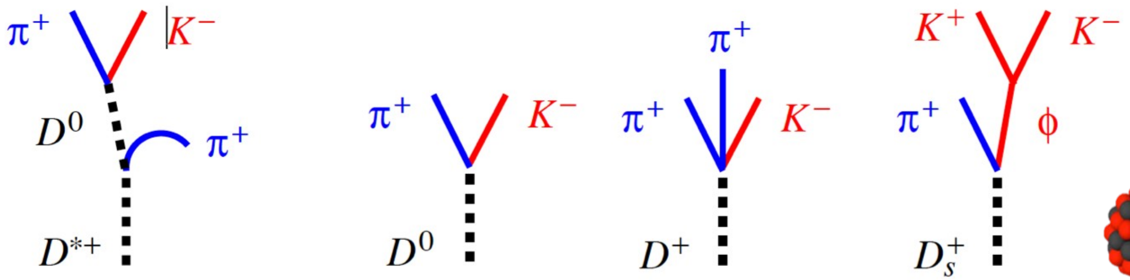
Mid-rapidity silicon vertex detector: 2 barrel layers MAPS or other silicon detector.

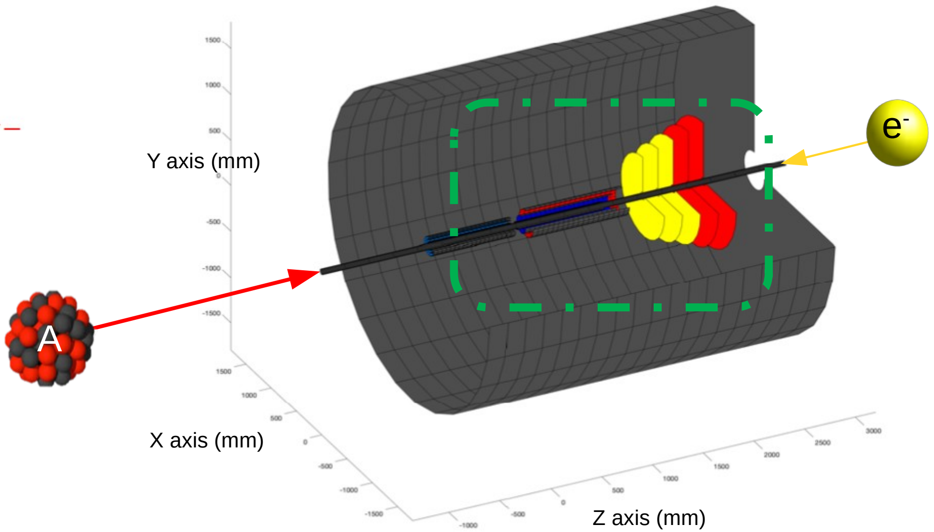
Forward-rapidity silicon tracking detector (FST): 5 forward planes of silicon detection.

Technology options are being studied in detail

R&D FST: Fast simulations

Goal is to measure heavy flavor products and their correlations in the forward direction at the EIC



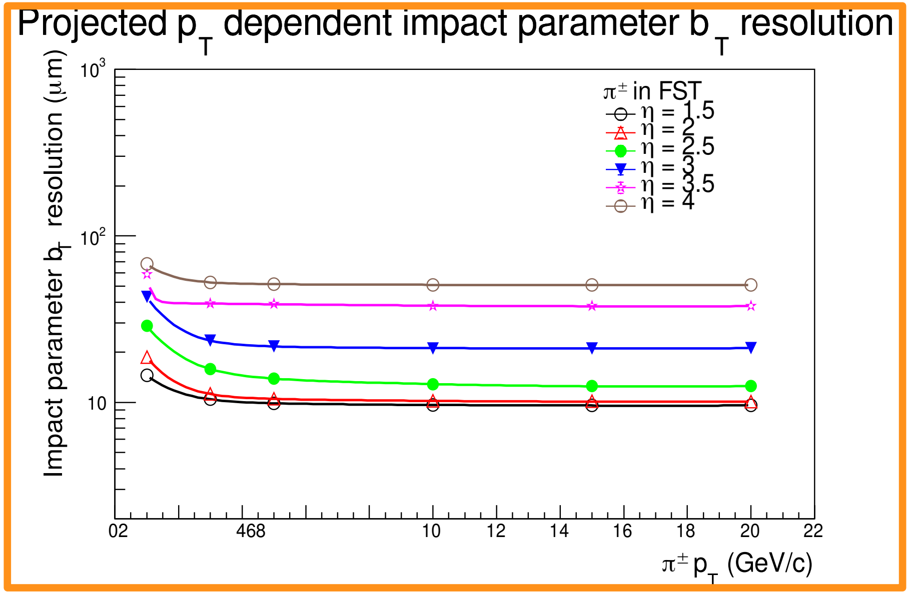


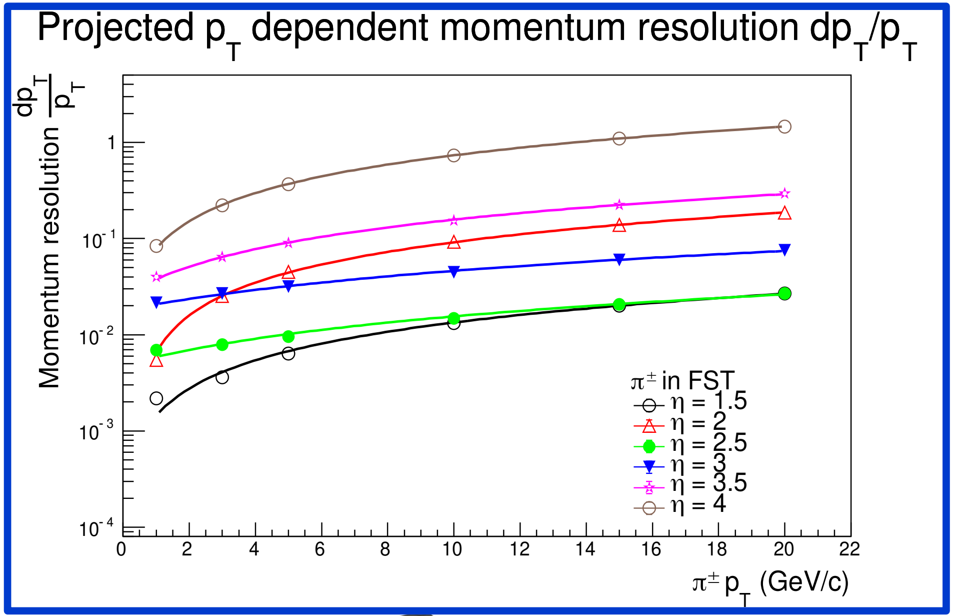
Fast simulations have been set up to explore detector performance:
pixel size, χ_0, trigger integration time...

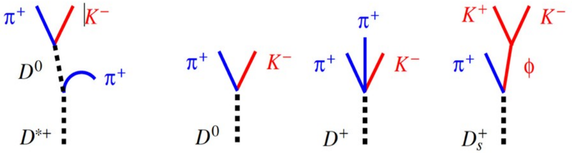
1 triggered event embedded with background events.

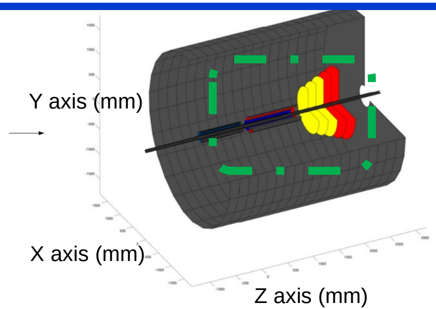
FST Fast simulations: Track performance

Tracks with p_T > 1 GeV/c, 1.5<η<4.0









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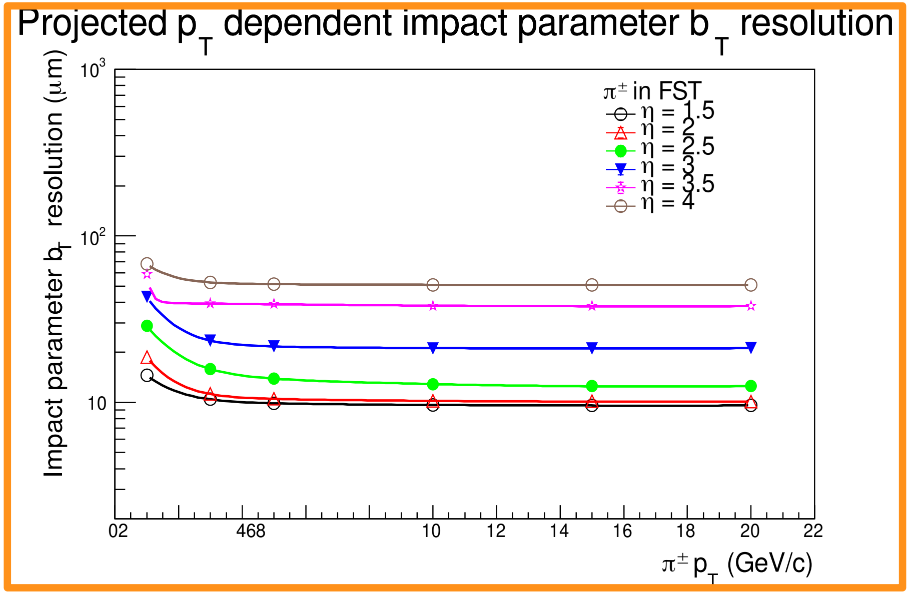
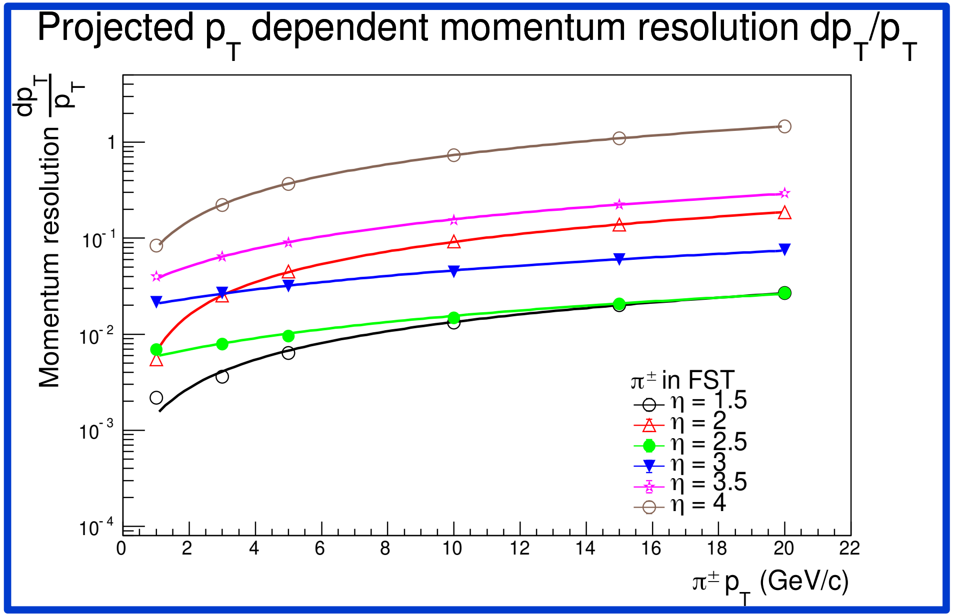
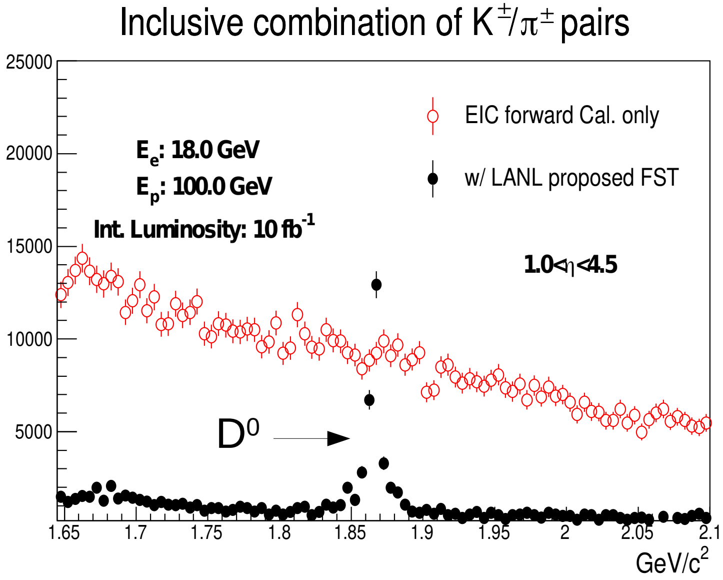


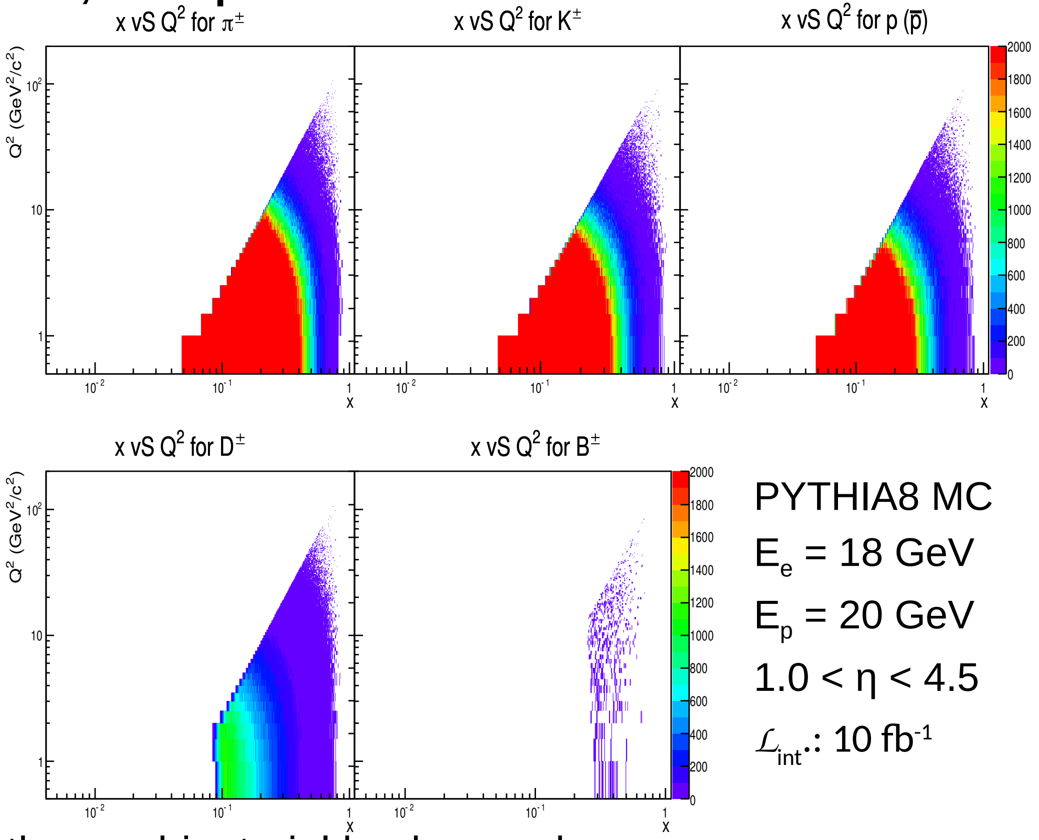


- Left: 70 µm resolution or better can be achieved by the initial FST design
- Right: preliminary momentum resolution, dp_T/p_T , is in line with the EIC detector handbook (forward tracking requirements.)

FST Fast simulations: Particle reconstruction

Tracks with p_T > 1 GeV/c, 1.5<η<4.0





PYTHIA8 MC

E_e = 18 GeV

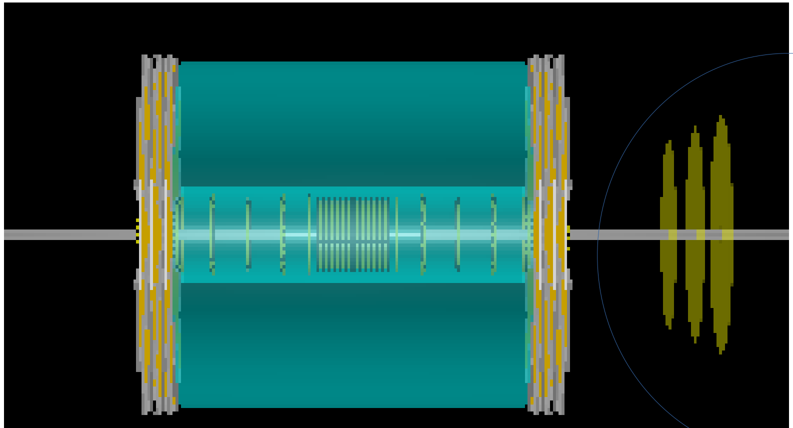
E_p = 20 GeV

1.0 < η < 4.5

$\mathcal{L}_{int}$.: 10 fb^{-1}

- Identification of D^0 mesons while reducing the combinatorial background
- Hadron reconstruction in a wide kinematic region.

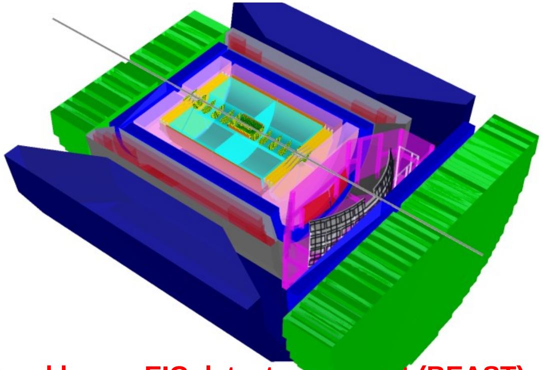
FST R&D Full simulations



Integration of the detector

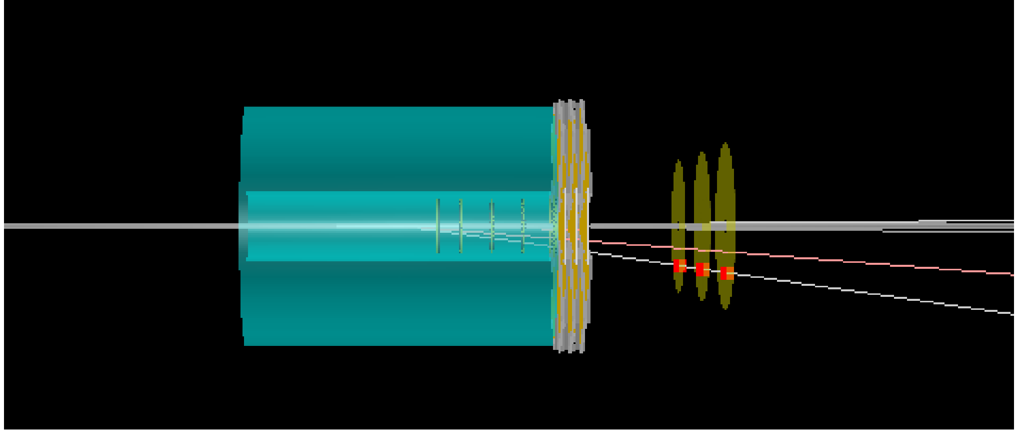
Full Simulations:

- Ongoing exploratory work in ep and eA Montecarlo simulations with existing EIC tools (EICRoot)
- Integration with other detectors.



Brookhaven EIC detector concept (BEAST)

ep event (Geant4) + forward region detectors+ TPC



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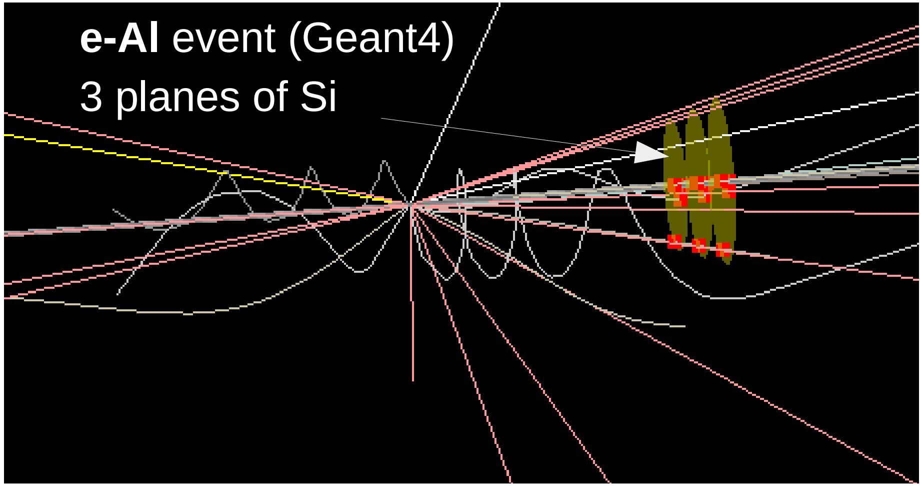
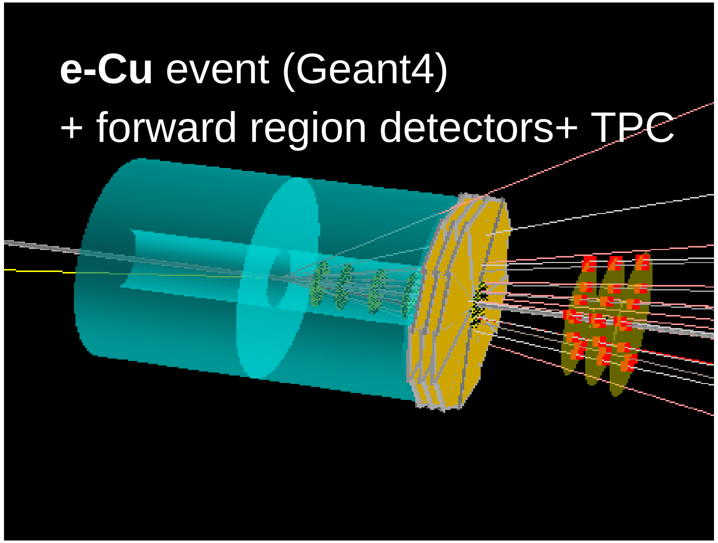
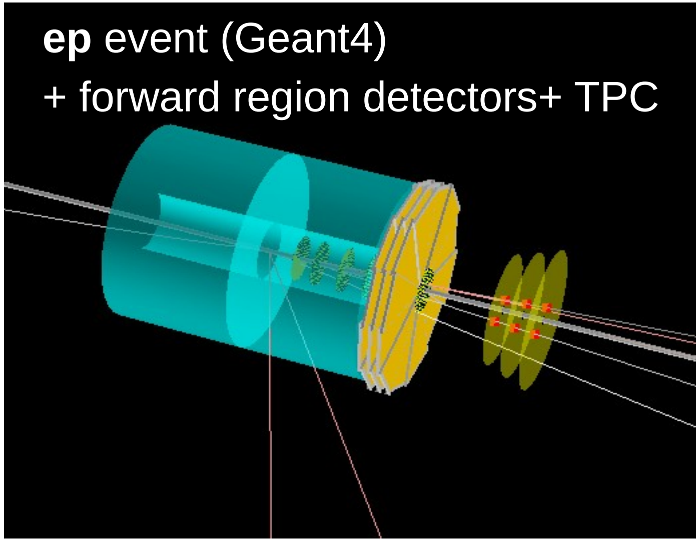


Full Simulations:

- We are currently working towards a longer term full detector simulation.





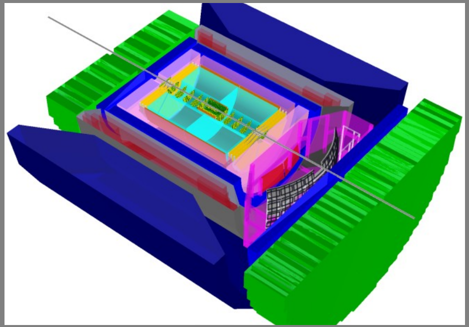
Full simulations a brief status

A variety of EIC specific simulations have been implemented by EIC collaborators.

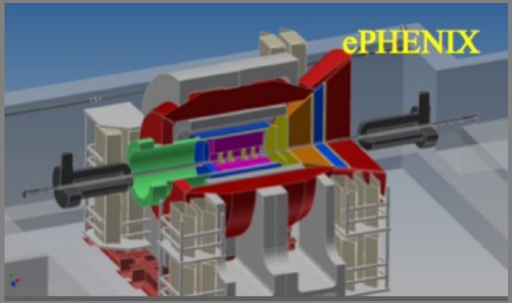
All will need revisiting/updating. Ongoing effort by the EIC R&D and software group.

Software is bound to existing detector concepts (see A Kiselev’s presentation CFNS PID workshop)

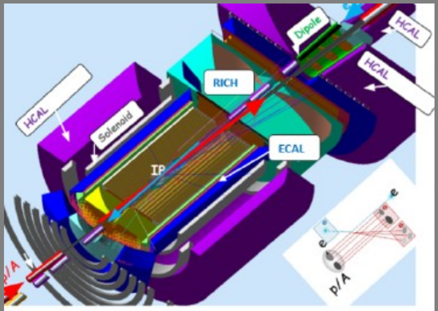
BEAST (BNL)



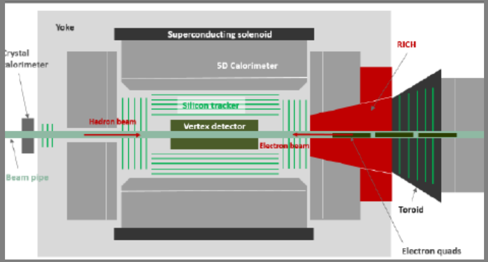
ePHENIX @RHIC



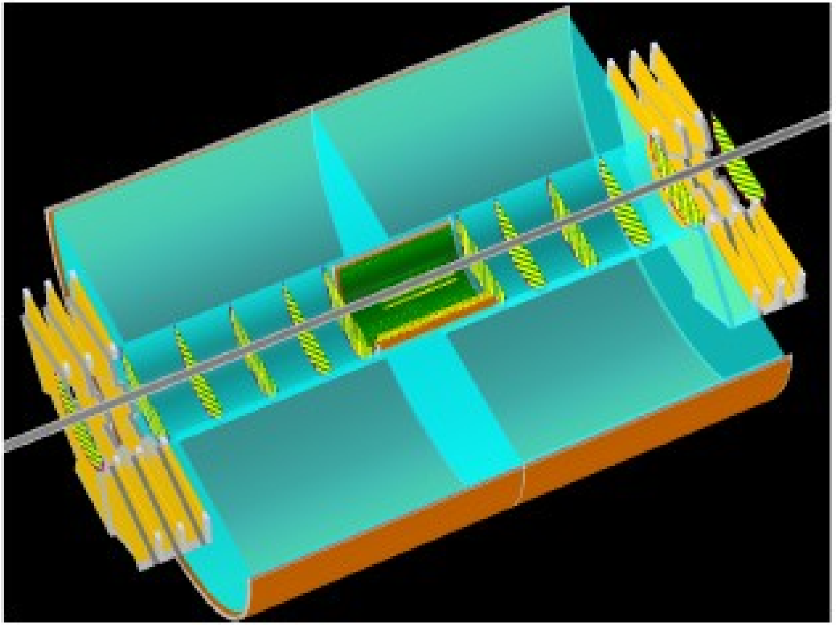
JLEIC (Jlab)



TOPSiDE (Argonne)

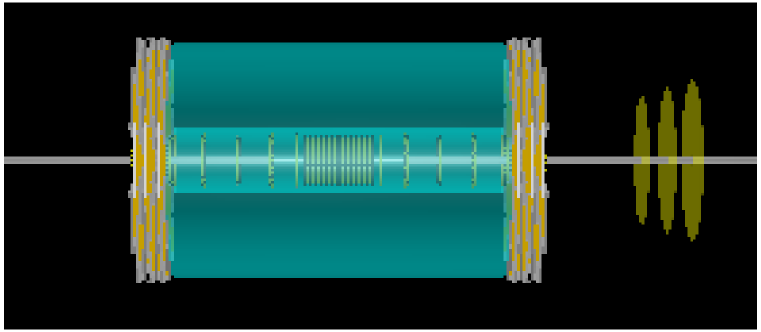


Full simulations a short selection



EicROOT- Modular Geometry:

- BeAST incorporated and flexibility to append detector in forward region (LEGO style)
- Tech support exists
- Tracking& vertexing rudimentary



see A Kiselev's presentation CFNS PID workshop

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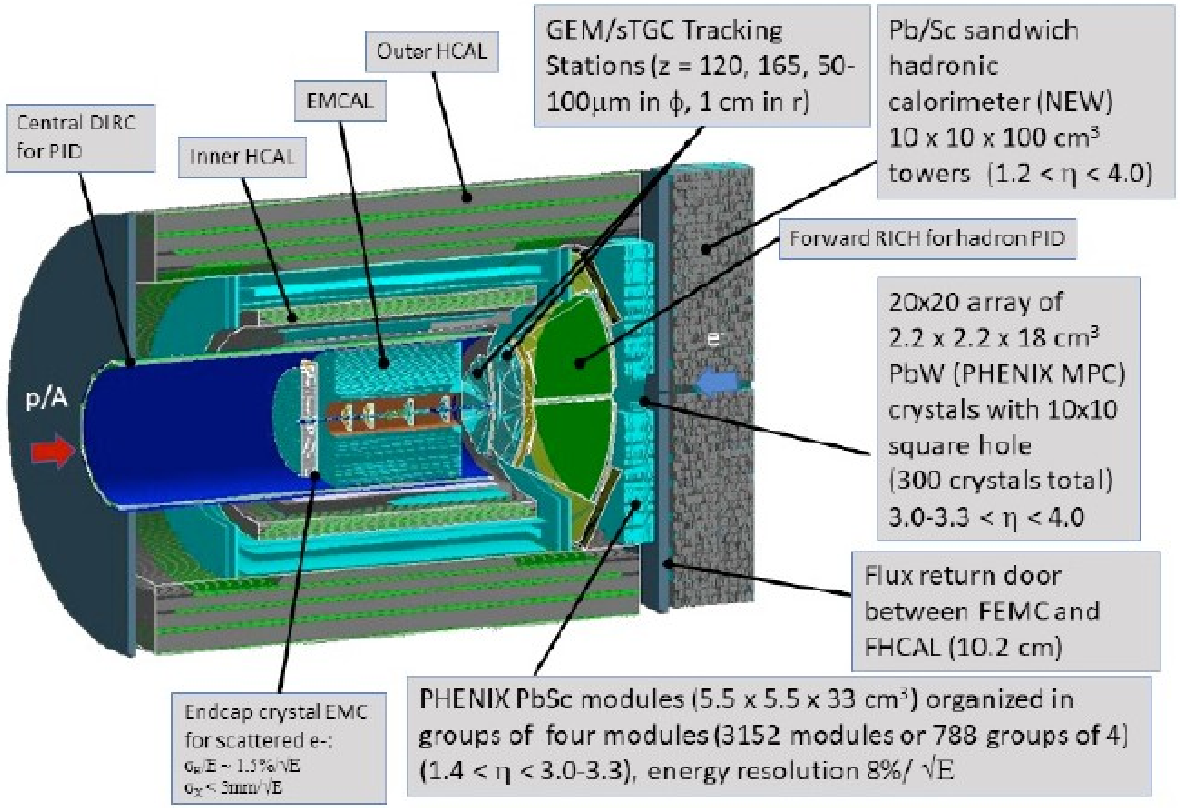

Fun4All- Short term future

- ePHENIX incorporated and ongoing work to append detector in forward region
- Tracking, vertexing , digitization
- Support exists

see A Kiselev’s presentation CFNS PID workshop

Full simulations a brief summary

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All will need revisiting/updating. Ongoing effort by the EIC R&D and software group.

Physics generators ep and eA (to name a few, most which we have tested)

- Pythia, PythiaeRHIC, SARTRE
- DPMJetHybrid
- BeAGLE: based on DPMJetHybrid.

Particle transport /Si simulation tools
- Geant3 → Geant4
- LiC, originally developed for ILC (eRD16 LBNL)

Software and detector geometry from ongoing EIC R&D
- EICRoot (BeAST geometry) GEANT-3
- Fun4All (ePHENIX/sPHENIX geometry) GEANT-4
- eJANA (Jlab) GEANT-4
- and more…

Final words

- Exciting times ahead for our field

- Lots of new collaborations are being forged and planned to achieve the physics program I described today

- A lot of work needs to be done before we get to detect heavy quarks in our EIC detectors and evaluate their signatures.

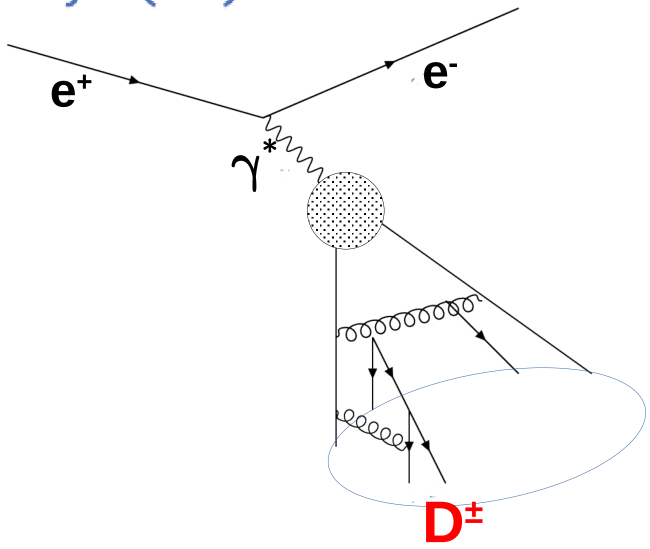
Extras

Focus: Heavy flavor hadrons, jets

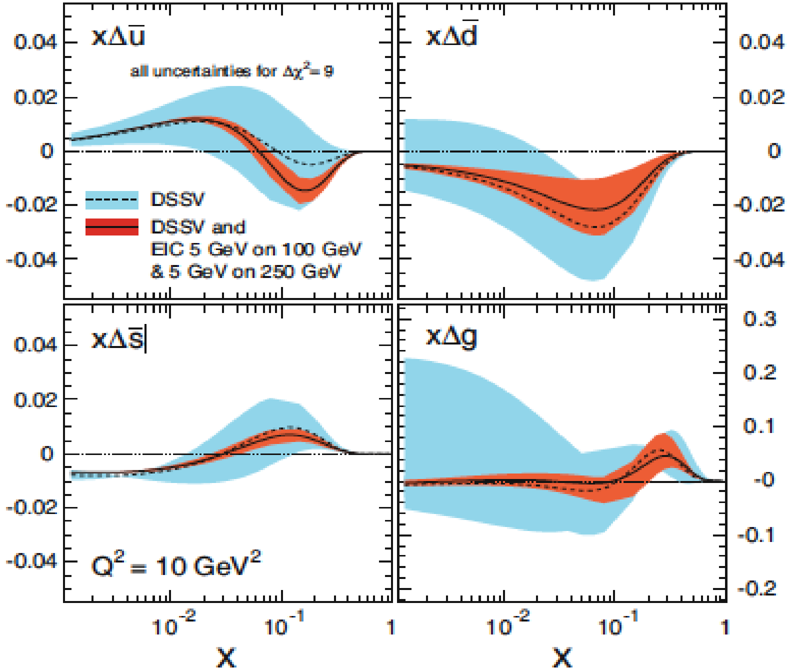
Heavy flavor hadrons, jets which can be treated as surrogates of initial quarks/gluons and their correlations in the hadron/nuclei going (forward) direction at the EIC.

- Determine the initial quark/gluon distribution functions in the poorly constrained kinematic region.
- Input for the evaluation of the quark/gluon fragmentation/hadronization processes.
- Provide further information on the gluon Sivers function and other spin observables.

$$e^- + p \rightarrow e^- + jet(D^\pm) + X$$



polarized PDFs



Vertex Detector Requirements

EIC Detector Requirements and R&D Handbook v1.1

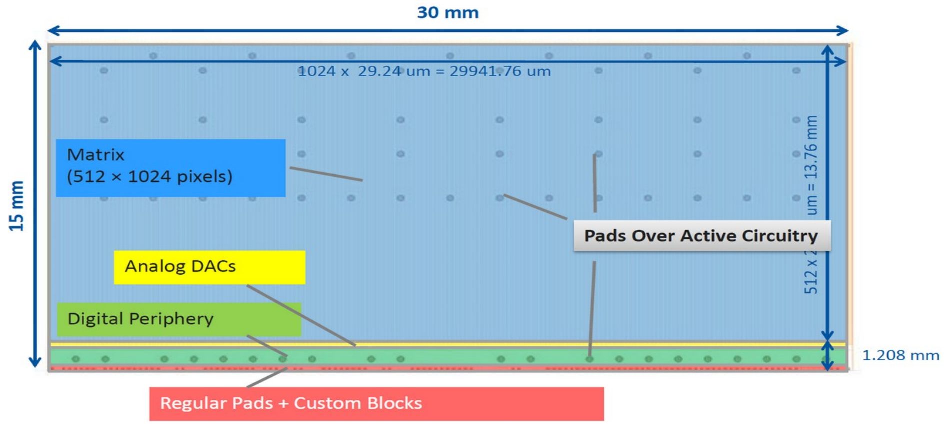
EIC Detector Requirements

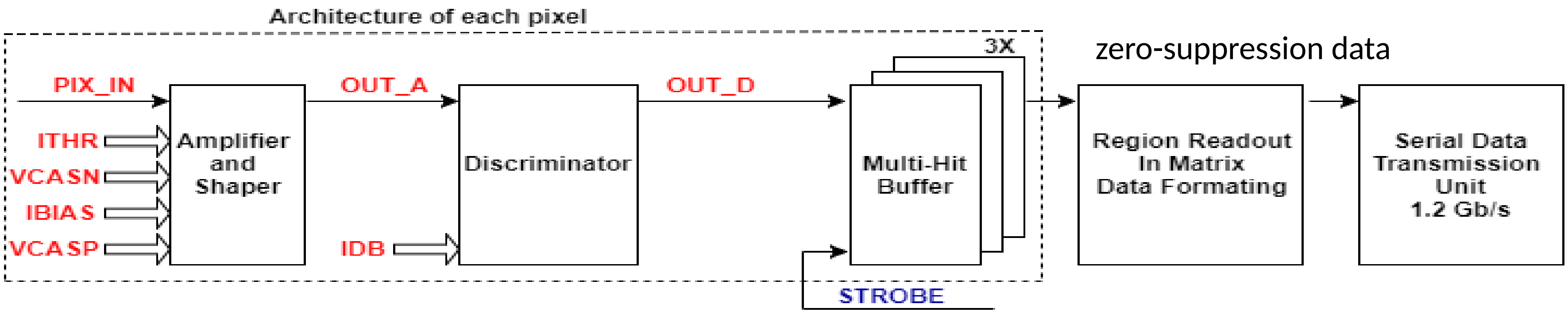
Table 2: Physics requirements for a an EIC detector

η	Nomenclature			Tracking			Electrons		π/K/p PID		HCAL	Muons
				Resolution	Allowed X/X_0	Si-Vertex	Resolution σ_E/E	PID	p-Range (GeV/c)	Separation	Resolution σ_E/E	
-6.9 — -5.8			low-Q^2 tagger	$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2								
...	↓ p/A	Auxiliary Detectors										
-4.5 — -4.0			Instrumentation to separate charged particles from photons									
-4.0 — -3.5												
-3.5 — -3.0				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$			$2\%/\sqrt{E}$					
-3.0 — -2.5												
-2.5 — -2.0			Backwards Detectors			TBD			≤ 7 GeV/c		~50%/$\sqrt{E}$	
-2.0 — -1.5				$\sigma_p/p \sim 0.05\% \times p + 1.0\%$			$7\%/\sqrt{E}$	π suppression up to 1:10^4				
-1.5 — -1.0												
-1.0 — -0.5												
-0.5 — 0.0		Central Detector	Barrel	$\sigma_p/p \sim 0.05\% \times p + 0.5\%$	~5% or les	$\sigma_{xyz} \sim 20$ μm, $d_0(z) \sim d_0(r\phi) \sim 20/p_T$ GeV μm + 5 μm			≤ 5 GeV/c	$\geq 3\sigma$	TBD	TBD
0.0 — 0.5												
0.5 — 1.0												
1.0 — 1.5												
1.5 — 2.0				$\sigma_p/p \sim 0.05\% \times p + 1.0\%$			0-12)%/$\sqrt{E}$		≤ 8 GeV/c			
2.0 — 2.5			Forward Detectors			TBD					~50%/$\sqrt{E}$	
2.5 — 3.0									≤ 20 GeV/c			
3.0 — 3.5				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$					≤ 45 GeV/c			
3.5 — 4.0			Instrumentation to separate charged particles from photons									
4.0 — 4.5												
...	↑e	Auxiliary Detectors										
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\|t\|)/\|t\| < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								

Monolithic Active Pixel Sensor (MAPS)

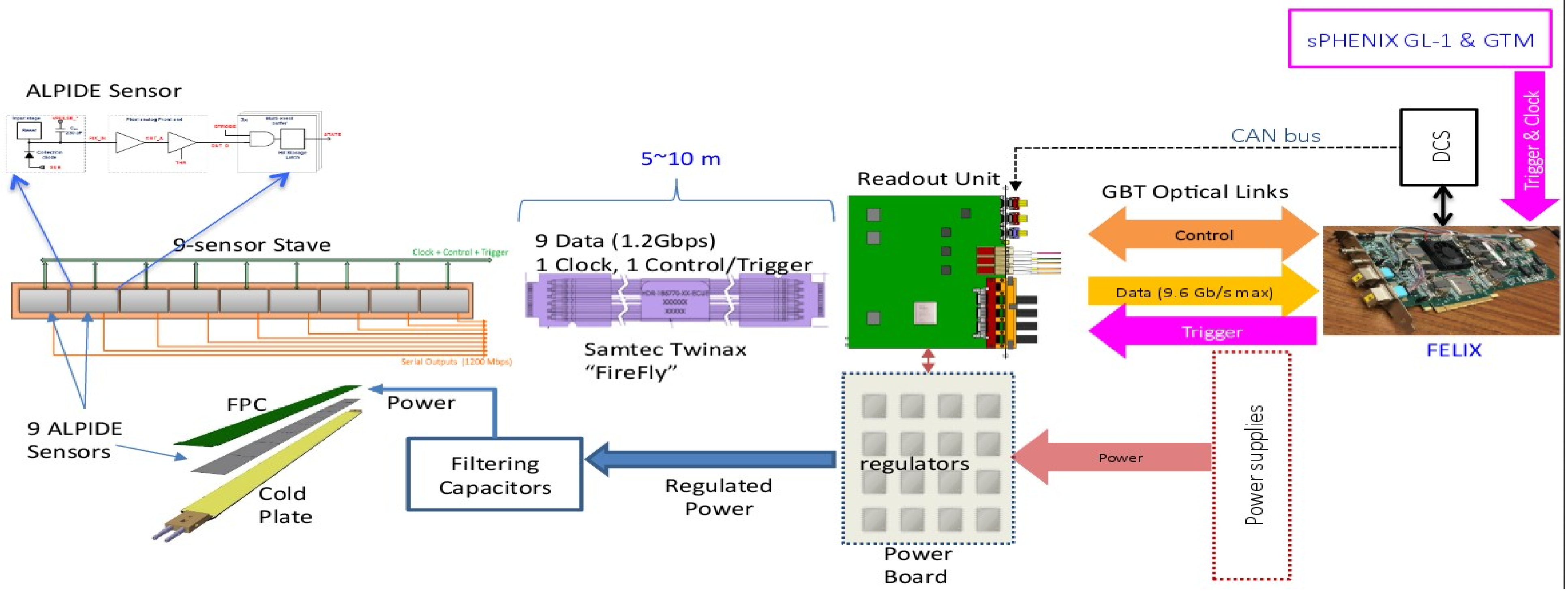
- The ALPIDE chip used for ALICE ITS upgrade and sPHENIX MVTX detector.
- 1024X512 pixels locate in the 3.0cmX1.5cm active region. Each pixel contains the charge sensitive amplifier, discriminator and 3 hit buffer.
- 11M channels in a 10X10 cm^2 active region.





Readout chain of the MAPS

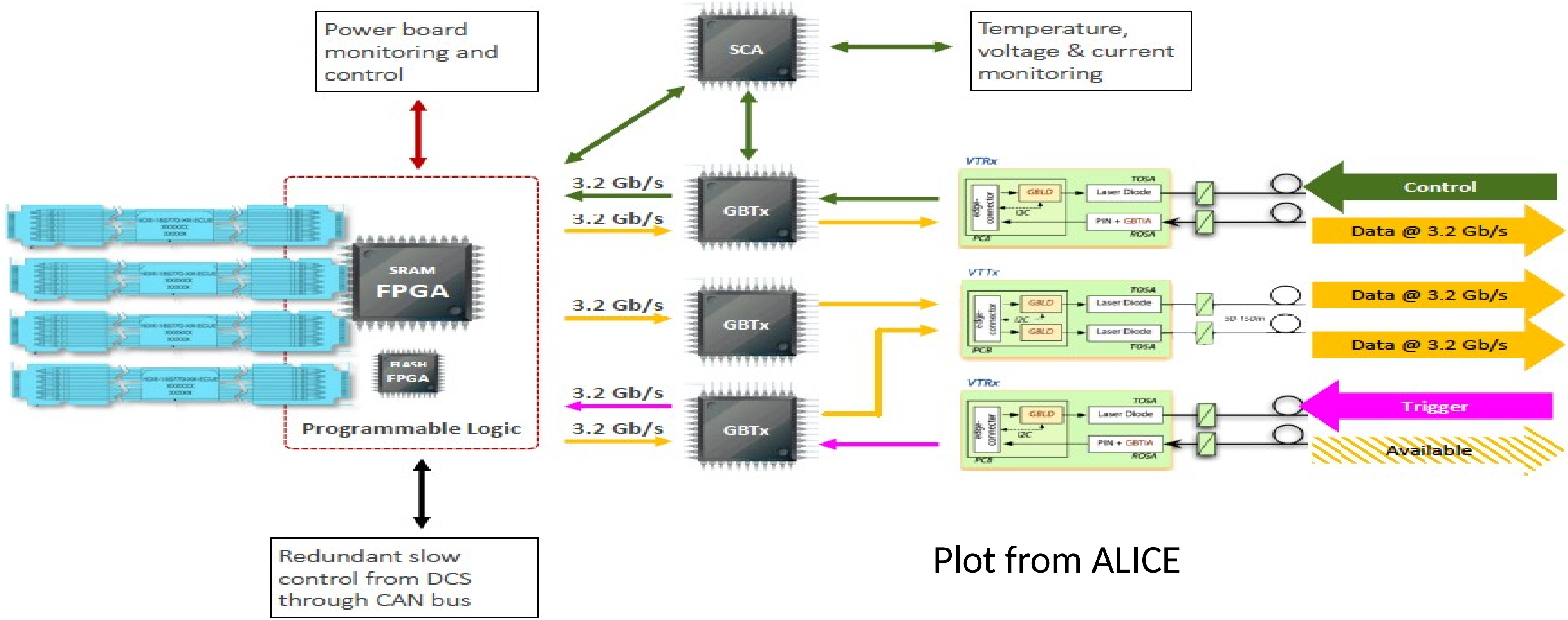
- Under R&D. Take the sPHENIX design for example:



- **Although the spatial resolution can reach ~ 5 μm, but the typical integration time is ~5 μs.**

Readout components for MAPS

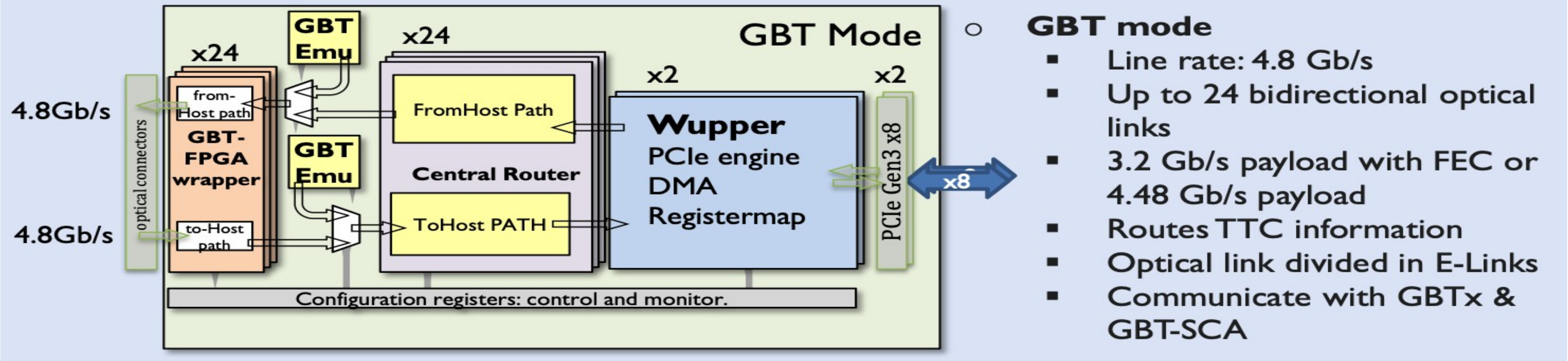
- Front end electronics – the Readout Unit (RU):
- One RU can read one stave with 9 ALPIDE sensors.



Plot from ALICE

Readout components for MAPS

- Back end electronics – the Felix board, the full integration still under R&D:
- Use the GBT mode, one Felix board can read 4 RUs connected with 4 staves.



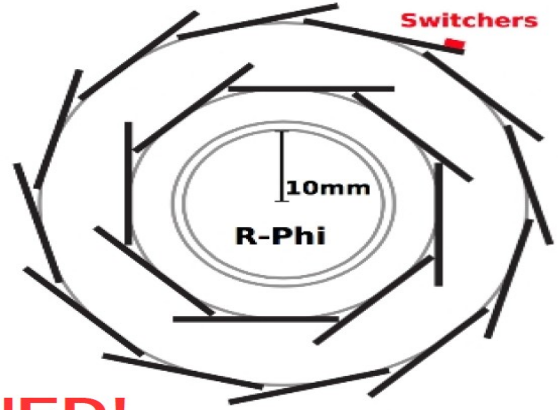
Plot from ATLAS

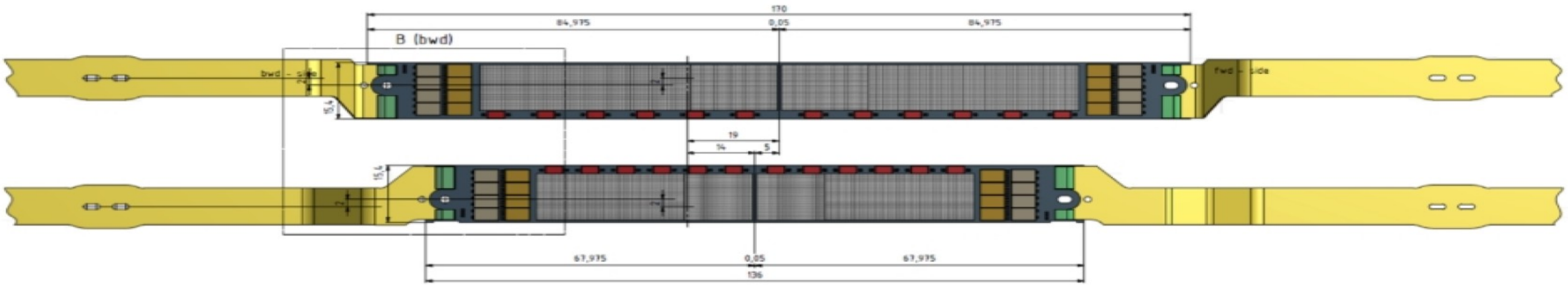
DEPFET modules

- Used for the PXD detector of Belle II experiment.
- Frame rate 50 kHZ.
- 2.4M – 3.6M channels in a 10X10 cm² active region.

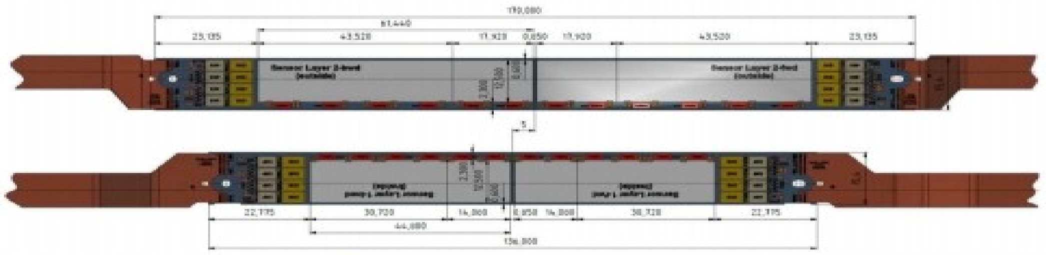
	Layer 1	Layer 2
Module	8	12
Radii	14 mm	22 mm
Ladder Size	15x136 mm^2	15x170 mm^2
Pixel Size	50x55 μm^2 50x60 μm^2	50x70 μm^2 50x85 μm^2
Pixels	250x1536	250x1536
Thickness	75 μm	75 μm

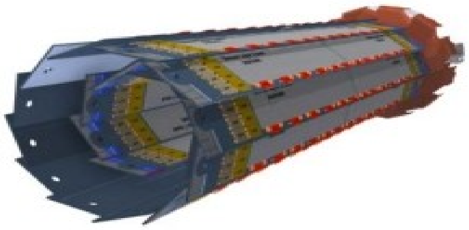
THINNED!

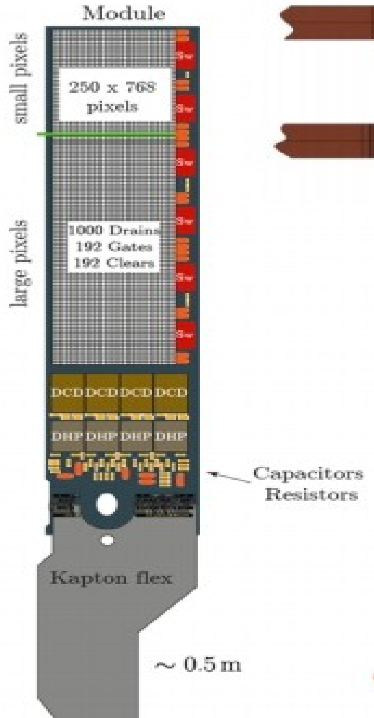




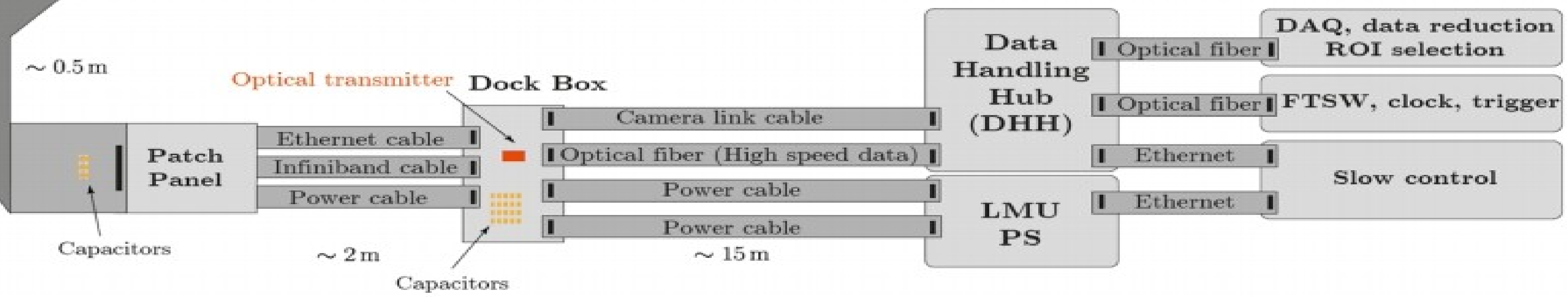
Belle II PXD readout schematics





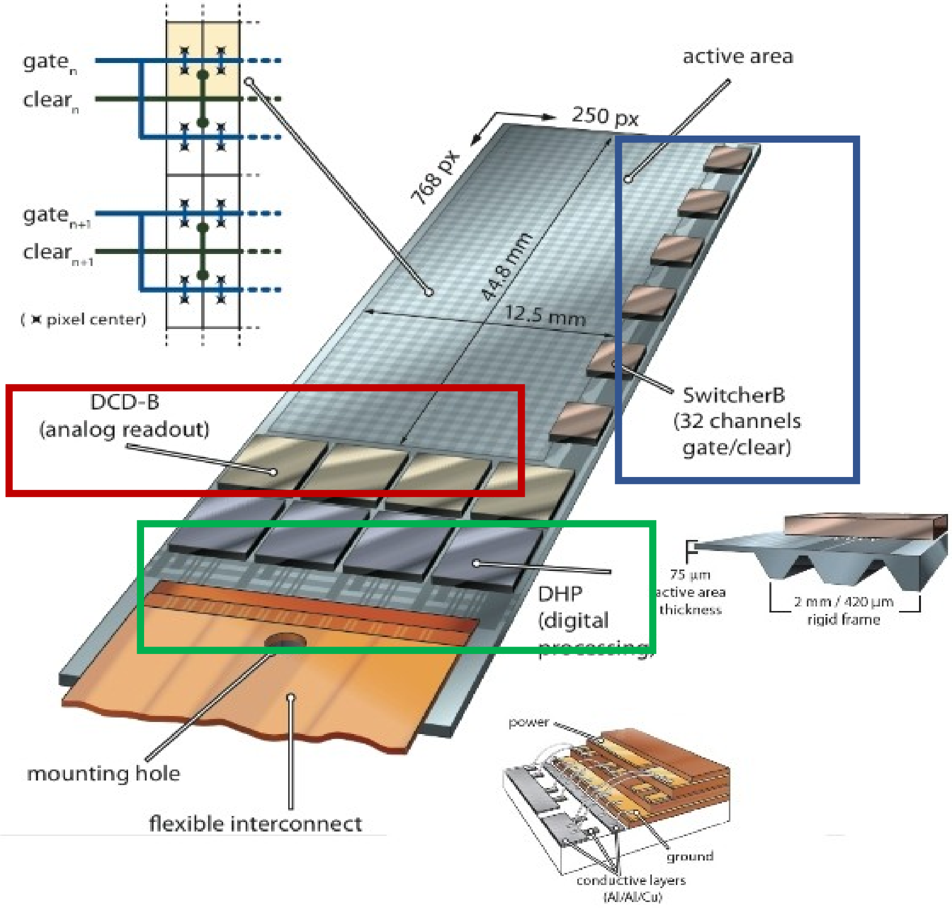


	Belle II PXD	
Radii	14, 22	mm
Sensitive length	90 (L1), 122 (L2)	mm
Sensitive width	12.5 (L1-L2)	mm
Number of ladders	8, 12	
Pixel size	55x50 & 60x50 (L1), 70x50 & 85x50 (L2)	μm^2
r/o time per frame	20	μs
Number of pixels	8	Mpix



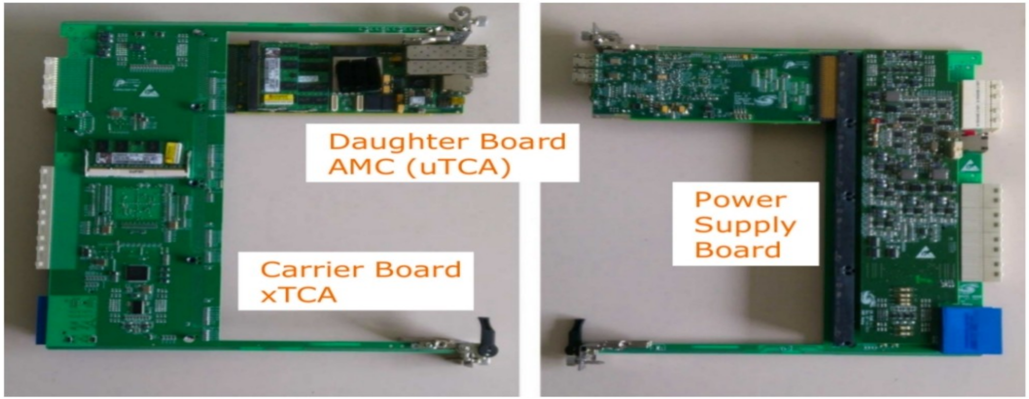
Belle II PXD single module ASICS

- DCDB (Drain Current Digitizer)
  - ADC (for electrical current)
  - UMC 180 nm
  - 256 input channels
  - 8-bit ADC per channel
  - 92 ns sampling time
  - Rad hard tested (7 Mrad)
- DHP (Data Handling Processor)
  - IBM CMOS 90 nm, TSMC 65 nm
  - Zero suppression
  - Pedestal correction
  - Timing and trigger control
  - Rad. Hard tested (100 Mrad)
- SwitcherB (Row Control)
  - AMS/IBM HVCMOS 180 nm
  - Gate and Clear signal
  - 32x2 channels
  - Fast HV ramp for Clear
  - Rad. Hard tested (36 Mrad)



Courtesy of Xuan Li (LANL)

Belle II PXD backend readout system



ONSEN AMC card
v4.0 (final)
Virtex-5 FX70T
2 optical links (6.25 Gbps)
GbE

ONSEN xTCA carrier card
v3.3 (final)
Virtex-4 FX60 (switcher to ATCA backplane)
GbE

add-on:
RTM board
power supply board